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Prototype equipment to measure co-channel interference on 625-line television signals

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PROTOTYPE EQUIPMENT TO MEASURE CO-CHANNEL INTERFERENCE ON 625-LINE TELEVISION SIGNALS

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Summary

This report describes prototype equipment designed to measure the level of co-channel interference (c.c.i.) on a 625-line television signal.

The c.c.i. measuring equipment's primary application is at transmitters fed by re-broadcast links (r.b.l.) where it would measure the level of c.c.i. on the incoming television signal and record it on a chart recorder. The c.c.i. measuring equipment can distinguish between c.c.i. sources with different frequency offsets between wanted and interfering carriers and so in many cases can identify the interfering sources.

The report discusses in detail the fundamental and instrumental limits on the performance of the c.c.i. measuring equipment. The report concludes that this equipment should be able to measure levels of c.c.i. close to the limits of perceptibility. There are, however, some limits to performance which can be assessed accurately only after extensive field trials. When these field trials are complete, it is hoped that the prototype equipment will form the basis for a production model.

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PROTOTYPE EQUIPMENT TO MEASURE CO-CHANNEL INTERFERENCE ON 625-LINE TELEVISION SIGNALS

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1. Introduction

As the u.h.f. television transmitter network grows, each channel must be used more often. Hence, there is an increasing possibility of co-channel interference (c.c.i.) affecting television reception. Interesting work[1] has been done on removing c.c.i. due to television signals with one type of frequency offset but no method has yet been found that can completely eliminate the effects of c.c.i., particularly in the case of multiple interference. One aspect of this problem concerns transmitters whose programme feed depends on a re-broadcast link (r.b.l.).

An r.b.l. transmitter receives a u.h.f. television signal from another transmitter, changes its frequency, and then re-broadcasts the signal to its own service area. If c.c.i. is present on the incoming television signal, then reception throughout the second transmitter's service area will be impaired. It is desirable to be able to measure the level of c.c.i. on the incoming television signal in order to determine whether or not the level of c.c.i. is acceptable for re-transmission. If it is not acceptable, this will normally mean that measures must be taken to improve reception. For example, the directivity of the r.b.l. receiving aerial may have to be increased to give better rejection of the interfering sources, or a separate receiving site may be necessary, or an s.h.f. link may be installed.

Consideration is, of course, given to this problem at the planning stage applying the available methods of field strength prediction; nevertheless, to obtain the best possible assessment, signals must be measured over a period of several months at the actual site of interest. This is because, with tropospheric propagation, the level of c.c.i. that is received varies with time. Typically, the level of c.c.i. may be imperceptible for most of the time, becoming easily visible for short spells lasting from several hours to several days spaced by many months. At present, the only method of measuring c.c.i. is by experienced assessment of the television picture when displayed on a monitor. Continuous observation over many months would be extremely expensive and hence, there is a need for equipment which can automatically record the level of c.c.i.

A prototype measuring equipment described in this report has been developed to record the level of c.c.i. on the incoming television signal at r.b.l. transmitters. The c.c.i. measuring equipment operates on the demodulated video signal and measures the variation in level of the line synchronising pulses caused by the beat between the wanted and interfering carriers. This method and the digital processing of the sampled synchronising pulses were first suggested by G.D. Monteath.

2. Operational requirements

For useful results the equipment should be able to record levels of c.c.i. close to the limit of perceptibility. The visibility of the interference pattern on the received picture depends on the frequency difference or 'offset' between the wanted and interfering carriers as well as on their relative amplitudes.[2] The interference pattern is most visible when the carrier offset is close to a multiple of the line-scan frequency. Ignoring the effects of precision offsets, the visibility decreases gradually as the offset frequency is moved towards an odd harmonic of a half line-scan frequency.

Within the United Kingdom the chosen nominal carrier offset between two co-channel transmitters is either zero, $\pm{}^{5}/_{3}$ line or $\pm{}^{10}/_{3}$ line frequency. The frequency tolerance for each transmitter is ± 500 Hz and so the offset frequency between two transmitters may drift by ± 1 kHz.

For nominal ${}^{5}/_{3}$ and ${}^{10}/_{3}$ line offsets, the limit of perceptibility is reached at a carrier ratio of 50 dB, while for nominal zero-offset interference, the limit of perceptibility occurs when the carrier ratio is 60 dB[2] so that, of the two offsets, the latter is the more difficult case to measure in terms of subjectively significant levels. The sensitivity of the measuring equipment is limited by a number of factors and for practical reasons has been designed to resolve c.c.i. on all nominal offsets when the carrier ratio does not exceed about 50 dB.

3. Principles of operation

A 625-line television signal amplitude-modulates a u.h.f. carrier with a negative polarity of modulation so that the peak amplitude of the carrier occurs during the line and field synchronising pulses. In the absence of co-channel interference, the peak amplitude of the u.h.f. carrier at a receiving site should be constant. This ignores slow variations caused by fading.

If a co-channel signal is also present at the receiving site, then the amplitude of the wanted carrier at the tips of the synchronising pulses will be modulated by the beat between the wanted and interfering carriers. When the u.h.f. signal is demodulated, the signal level at the tips of the synchronising pulses will be modulated by the c.c.i. beat, the depth of modulation being proportional to the ratio of the interfering to wanted carrier-levels. The frequency of the variation is the frequency difference between the co-channel carriers.

The c.c.i. measuring equipment takes samples of every line synchronising pulse of the demodulated video signal at line-scan frequency. It measures the variation

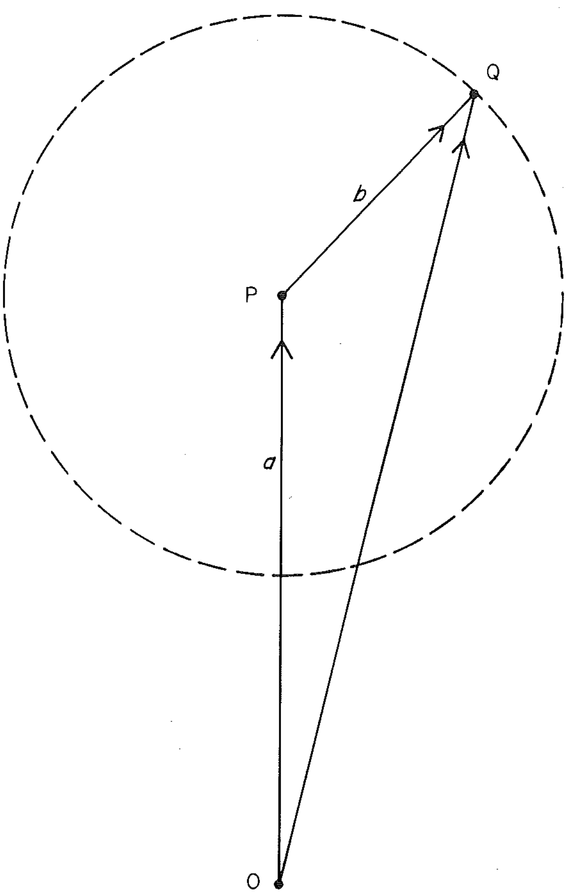

Fig. 1 - Vector diagram of wanted and interfering carriers

OP = *Wanted carrier at tips of syncs*
PQ = *Interfering carrier*
OQ = *Resultant*

in the pulse level, relative to an arbitrary datum, caused by the beat between the wanted and interfering carriers.

After sampling at line frequency, all the beat-frequency information lies in the range zero to half line-frequency. However, the difference between the offset frequency and the nearest harmonic of line frequency is preserved. For example, after sampling, ± $^{5}/_{3}$ line-scan frequency and ± $^{10}/_{3}$ line-scan frequency inputs become $^{1}/_{3}$ line frequency. The equipment cannot therefore distinguish between $^{5}/_{3}$ and $^{10}/_{3}$ line offsets. For assessing the total interference, however, it is not essential to do so as both produce the same picture impairment.

The amplitude of the variations in the level of the sync. pulses for a specified level of c.c.i. can be found from the vector diagram shown in Fig. 1. In Fig. 1, OP represents the amplitude a of the wanted carrier at tips of syncs. and PQ, the interfering carrier amplitude b. For simplicity, the interfering carrier is initially assumed to be unmodulated. The amplitude of the interfering carrier shown in Fig. 1 corresponds to the peak amplitude when modulated by video. Hence the carrier ratio (in dB) is

$$20 \log_{10} (a/b) \qquad (1)$$

The percentage of modulation of the resultant carrier (OQ) produced by the beat between the two carriers is

$$100\ b/a \qquad (2)$$

When the signal is demodulated to video, the peak-to-peak amplitude of the beat cycle superimposed upon the level of the sync. pulses will be

$$2\text{A}\ b/a \text{ volts,} \qquad (3)$$

where A is the peak-to-peak amplitude of a video signal giving 100% amplitude modulation of the wanted carrier. For a standard level video signal of IV from tips of syncs to peak white, A = 1·34 volts.[3]

In practice, the interfering carrier will be modulated by a video signal. Only on rare occasions will the line sync. pulses of the wanted and interfering signals coincide. Generally, the sync. pulses of the wanted signal will occur during the active line period of the interfering signal. Hence the amplitude of the beat cycle on the wanted sync. pulses will change as the interfering picture content changes. The mean amplitude of a carrier modulated by video is typically 6 dB below the peak. Hence the mean value of the peak-to-peak amplitude of the beat cycle superimposed on the sync. pulse level will be

$$1{\cdot}34\ b/a \text{ volts} \qquad (4)$$

It is often useful to express the amplitude of the beat cycle in the sync. pulse level in terms of the ratio of peak-to-peak picture to r.m.s. interference. Assuming that the beat cycle is sinusoidal, its r.m.s. amplitude is

$$\frac{1{\cdot}34\ b}{2\sqrt{2}\,a} \text{ volts} \qquad (5)$$

The luminance signal in a video waveform is usually taken as a reference; its peak-to-peak value is 0·7 volts. Hence the peak-to-peak picture (luminance) to r.m.s. interference ratio is

$$0{\cdot}7\ \frac{2\sqrt{2}\,a}{1{\cdot}34\,b} \qquad (6)$$

and, from Expression (1), the ratio peak-to-peak picture to r.m.s. interference (in dB) is

wanted/interfering carrier ratio (dB) + 3·4 dB (7)

The wanted/interfering carrier ratio is a measure of the effective protection ratio achieved at any given time.

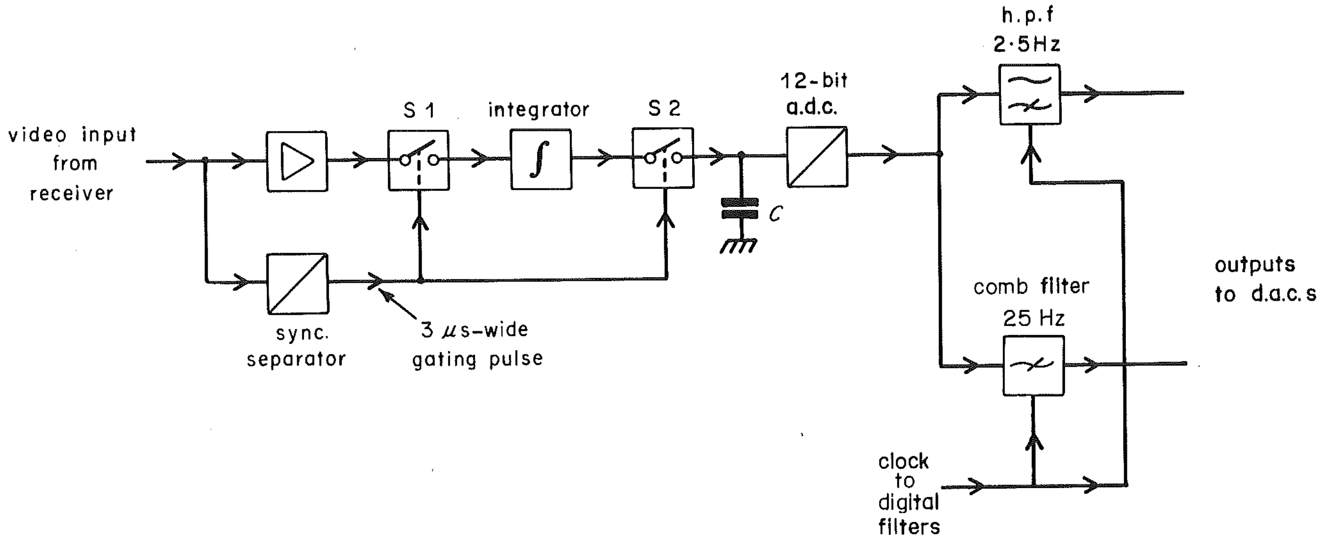

Fig. 2 - Sampling and digital filter circuits

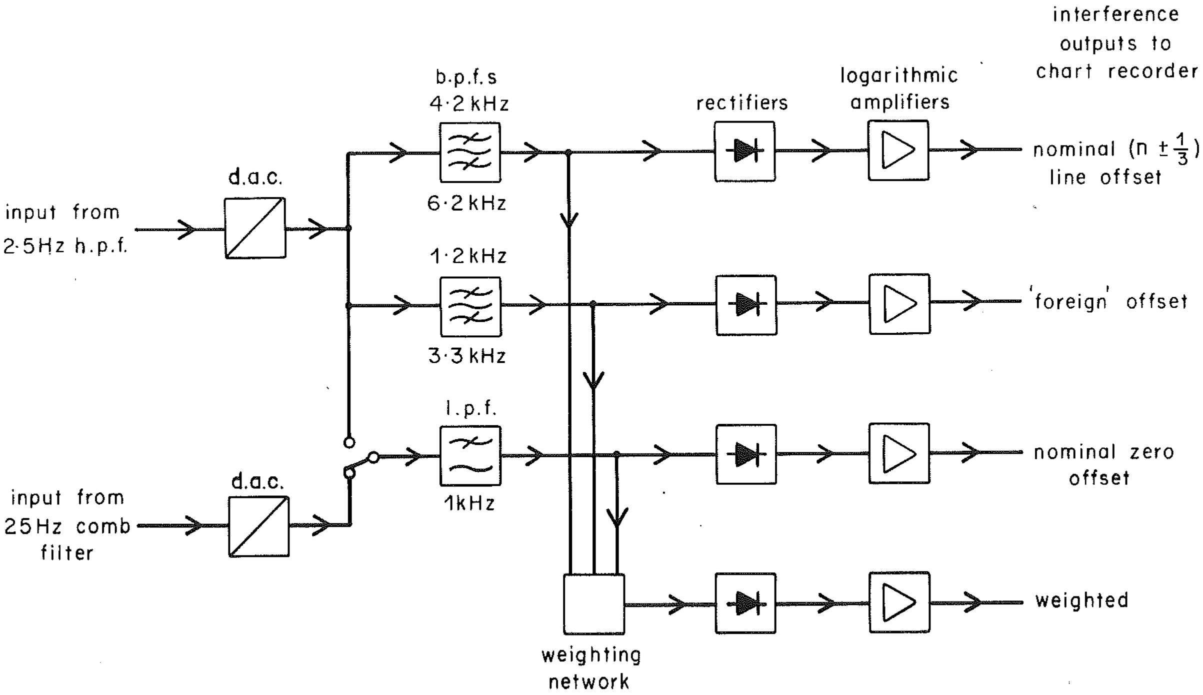

Fig. 3 - Offset filters and logarithmic detectors

4. Description of the prototype c.c.i. measuring equipment

4.1 General

Block schematic diagrams of the c.c.i. measuring equipment are shown in Figs. 2 and 3. Fig. 2 shows the sampling and digital filter units Fig. 3 shows the offset filters and logarithmic detector units.

The video signal input to the measuring equipment comes from a television receiver tuned to the desired channel. The performance of this receiver does not need to be up to r.b.l. receiver standards. All that is required is that it has a good noise figure and stable tuning. For this reason, a commercially-made semi-professional television receiver has been used. The signal input to this receiver is taken from the u.h.f. feed to the r.b.l. receivers or transposers, using a suitable directional coupler.

4.2 Sampling and digital filter circuits

The accuracy and resolution of the c.c.i. measuring equipment can be improved by not sampling the level of the sync. pulses during the field blanking interval. Before starting this investigation, it was known that the level of the transmitted carrier at the sync. tips during the field blanking interval is not so constant as it is during the active field period. There is often a difference in level between the broad field pulses, the equalising pulses and the line sync. pulses. These variations in level would not in any way affect a displayed picture as they are very small. However, the variations are large enough to impair the resolution of the c.c.i. measuring equipment.

The field blanking interval can be easily removed if all the processing of the sampled sync. pulses is done in the digital domain. A similar operation in the analogue domain would be very difficult to instrument and a digital approach is justified on these grounds alone. The clock pulses to the digital circuitry can be stopped during the field blanking interval. This method has been adopted within the measuring equipment. The clock pulses to the digital circuits are stopped for 30 line periods embracing the field blanking interval.

Referring to Fig. 2, 3 μs of the central portion of each line sync. pulse is gated out by the switch S1. The level of each sync. pulse is averaged over the 3 μs period by the integrator. This reduces the noise bandwidth from 5·5 MHz to 165 kHz, without affecting the resolution to c.c.i. by more than 0·5 dB at $^{10}/_3$ line offsets. The integrator is 'leaky'; its output decays to zero between sync. pulses. The output voltage of the integrator at the end of the 3 μs period is stored by the capacitor C.

The level of each line sync. pulse, averaged over 3 μs, is converted into a 12-bit binary number by the 12-bit analogue-to-digital converter (a.d.c.). The conversion range of the a.d.c. is adjusted so that 0 dB c.c.i. (unity wanted/interfering carrier ratio) would occupy its full range, but the output display will reach full scale at a lower c.c.i. level.

The d.c. component of the sampled sync. pulses is removed by passing them through a 2·5 Hz high-pass filter. The output of this filter represents the variation in the level of the sync. pulses from their long term mean value. The filter is a first order recursive digital filter. It has a frequency response similar to that of a single-time-constant resistance-capacitance network. The operation of the filter is described in some detail in the Appendix.

4.3 Removing picture-dependent modulation of the level of the line synchronising pulses using a 25 Hz comb filter

The level of the sync. pulses of a video signal at the output of a television receiver is not constant. It is modulated by a low frequency 'rumble' which is picture dependent. The reasons for this modulation are:-

(1) The video signal output from the television receiver feeding the measuring equipment is a.c. coupled. As the mean luminance level of the picture changes, the level of the sync. pulses changes.

(2) The operation of the 'sync-tip a.g.c.' within the receiver is not independent of picture content.

(3) The level of the carrier at the sync. tips during the active field period from a transmitter is not constant. Again the variation is so small as not to affect normal displayed pictures. Variations are probably mainly due to inadequate power supply smoothing.

The television receiver feeding the measuring equipment was modified to lessen the importance of reasons 1 and 2. The capacitance of the post-detector coupling capacitors was increased and extra smoothing applied to the a.g.c. control voltage.

Despite the modifications to the receiver, the low-frequency picture-dependent 'rumble' in the sync. pulse level still reduced the resolution of the c.c.i. measuring equipment. The amplitude of the 'rumble' depends on the type of transmitter which is broadcasting the received signal and is generally equivalent to about −45 dB c.c.i.

Most of the energy of the 'rumble' is confined below 2 kHz and there is little energy in the frequency range of (n ± $^1/_3$) line offsets which, after sampling at line frequency, lie in the range 5·2 kHz ± 1 kHz. Hence, (n ± $^1/_3$) line offsets could be separated from the 'rumble' by a band pass filter. The resolution of the measuring equipment to (n ± $^1/_3$) line offsets would then be unaffected.

Unfortunately, the 'rumble' has most energy in the nominal zero-offset band where the greatest resolution to c.c.i. is needed. If the 'rumble' is not removed, then the resolution of the measuring equipment to zero offsets will be only −40 dB. This compares with the just-perceptible level of zero offset c.c.i. of −60 dB.

Picture-dependent modulation of the sync. pulse level can be reduced by passing the sampled sync. pulses through a 25 Hz comb filter. A stationary television picture is the same from picture to picture. Any picture-dependent modulation of the level of the sync. pulses will be the same from picture to picture. The 'rumble' will therefore have frequency components at harmonics of picture frequency (25 Hz) which will be removed by the comb filter.

When measuring nominal zero offset c.c.i. the sampled sync. pulses are passed through a 25 Hz comb filter as shown in Fig. 2. The output of this filter is formed by subtracting, from each input sample, the sample taken exactly 625 line periods earlier. The frequency response of the filter is of the sine-wave modulus form and is shown in Fig. 4. The dashed line indicates the mean response, 4 dB below the peak value.

Whenever the offset frequency between the wanted and interfering carriers is an exact harmonic of 25 Hz, the equipment will not respond to c.c.i. In practice, if the offset frequency is within a few hertz of a harmonic of 25 Hz the equipment will not respond as the interference at the output of the comb filter will be submerged in noise.

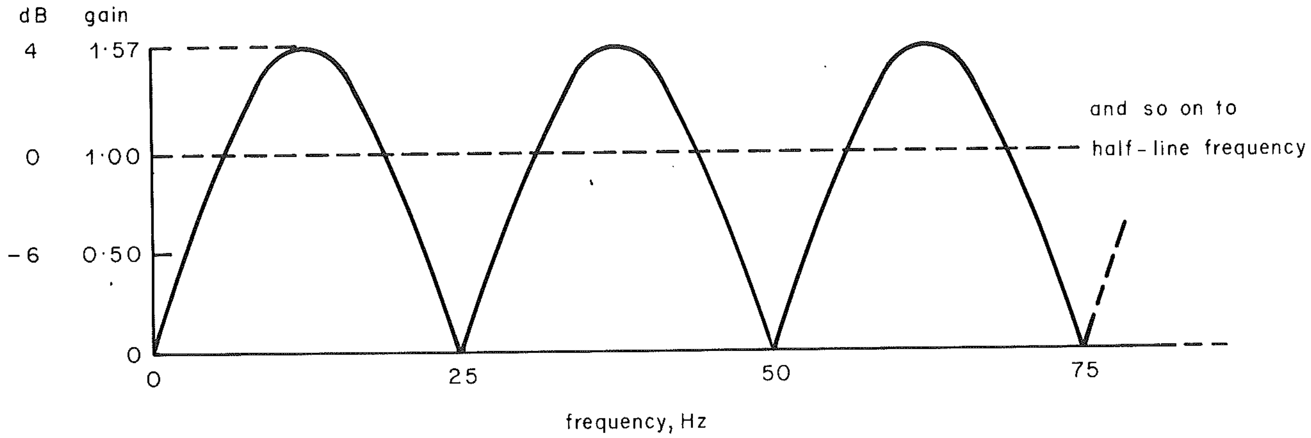

Fig. 4 - Frequency response of 25 Hz comb filter

For how long the interference remains invisible depends on the frequency stability of the two transmitters. No statistics are available of transmitter frequency stability at present. However, in the long term, the frequency of each transmitter is constant within ± 500 Hz. A short-term stability within a few hertz was therefore thought to be very unlikely. More recent investigations suggest that some main transmitters may drift only a few hertz per day. If this is the case, then, when measuring nominal zero offset interference between two main transmitters, the equipment could be insensitive to c.c.i. for several days.

It is assumed at present that the offset frequency will not stay within a few hertz of an exact multiple of 25 Hz for any appreciable time. The validity of this assumption will be found out during field trials. If the assumption is found to be false, then some other method for removing the picture-dependent modulation of the sync. pulse level will be used. Possible methods are discussed in Section 8.

4.4 Offset filters and logarithmic detectors

A block schematic diagram of the offset filters and logarithmic detectors is shown in Fig. 3.

The outputs of the 2·5 Hz high-pass and 25 Hz comb filters are converted to analogue signals by two digital-to-analogue converters (d.a.c.). Once the field blanking interval has been removed in the digital filters, there is no need for further digital signal processing. The offset filters and logarithmic detectors are easiest to make with analogue components.

The outputs of the digital filters are split into three frequency bands by the offset filters. The frequency bands correspond to c.c.i. with nominal zero offset, nominal (n ± $^1/_3$) line offsets and 'foreign' offsets. The 'foreign' offset band caters for adventitious local interference or possible interference from continental stations which may use non-standard offset frequencies. Also, it allows for the case when either the wanted or interfering transmitter has drifted outside its nominal frequency range.

The input to the nominal zero-offset filter can come from either the 2·5 Hz high-pass or 25 Hz comb filters. The normal connection is to the comb filter. If the level of zero offset interference is high enough to swamp the picture-dependent modulation of the sync. pulse level, then more accurate recordings can be made from the 2·5 Hz high-pass filter. If the comb filter is used, the equipment will not respond to interference when the offset frequency is close to a harmonic of 25 Hz.

A weighting network resistively adds the outputs of the offset filters according to their visibility on a television picture. The form of the weighting characteristic shown in Fig. 5 is derived from the protection ratios needed for c.c.i. arising from tropospheric propagation.[2]

The outputs of each of the three offset filters and the weighting network are rectified to detect the level of c.c.i. in each band. Ideally, the r.m.s. level of the c.c.i. should be measured. This would be more complex to instrument than a rectifying detector and was considered unnecessary.

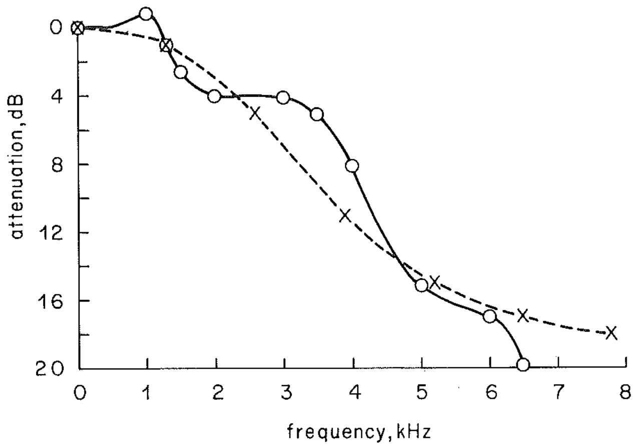

Fig. 5 - Response of weighting network
X-----X *Ideal* O——O *Measured*

The detector outputs are passed through logarithmic amplifiers which drive the chart recorder pens. Hence the level of c.c.i. at each offset is recorded on a linear scale of decibels. The maximum deflection that the measuring equipment can give corresponds to −14 dB c.c.i. and the zero deflection to −60 dB c.c.i.

4.5 Controlling time-switches

The operation of the c.c.i. measuring equipment is governed by two time-switches. A master time-switch switches on the complete equipment only during broadcasting hours. Normally, the equipment is switched on at 8.30 a.m. and off at midnight. The chart recorder is switched on by another time-switch for periods of between five and ten minutes each hour. The reasons for this choice are as follows.

As well as c.c.i., the measuring equipment will record anything that disturbs the level of the sync. pulses on the incoming video signal. There are numerous transient effects that can alter the sync. pulse level, the most important of these being aircraft flutter and shot changes in that order. No matter what the cause of the disturbance, they are recorded as a short spike on the trace. Normally, these transients do not affect the (n ± $^1/_3$) line and 'foreign' offset traces. It is unfortunate that the zero-offset output which needs the greatest resolution to c.c.i. is the one that is most affected by transients.

The frequency with which passing aircraft are recorded depends on how close the receiving site is to an airport or flight path. For example, at BBC Research Department, Kingswood Warren, which is midway between Heathrow and Gatwick airports, an aircraft is recorded every two or three minutes. In other parts of the country, the rate might be much lower.

To be able to distinguish between transient effects and c.c.i. the chart recorder must run at a rate greater than 1 cm per minute. For continuous recording at this rate, 10 metres of chart roll would be used per day.

To reduce the consumption of paper, the chart recorder is switched on automatically for only a few minutes per hour. In the prototype model, the recording times can be five minutes once every hour, five minutes once every half hour or 10 minutes once every hour. This should not affect the response to c.c.i., which normally rises in level over hours rather than minutes.

5. Limits to the resolution of the c.c.i. measuring equipment

5.1 Noise

It is reasonable to assume that the signal-to-noise ratio of the video signal feeding the c.c.i. measuring equipment is the same as at the output of the r.b.l. transmitter. The u.h.f. feeds to the measuring equipments receiver and the r.b.l. receivers are identical. Also, the noise figure of the measuring equipments receiver is comparable to that of r.b.l. receivers and transposers.

The specification[3] for the signal-to-noise ratio at the output of r.b.l. transmitters is 40 dB peak-to-peak picture to unweighted r.m.s. noise. This figure is quoted for the output of an ideal receiver with a v.s.b. filter at the output of the transmitter. The figure takes no account of noise added before the first transmitter in any one r.b.l. chain. It is the noise level on the sync. pulses that is of interest and 'noise-free syncs'. are inserted at the first transmitter. From Section 2, the level of c.c.i. that produces the same r.m.s. variation in the level of the sync. pulses as the above level of noise is −36 dB.

The c.c.i. measuring equipment averages each sync. pulse over a 3 μs period which reduces the noise bandwidth from 5·5 MHz to 165 kHz. This reduces the noise level by 15 dB so that it is now equivalent to −51 dB c.c.i. After sampling at line-scan frequency, the noise lies in the frequency range 0—½ line-scan frequency.

The noise bandwidth is further reduced by the offset filters. For the zero-offset filter, the noise bandwidth is 1 kHz and for the (n ± $^1/_3$) line offset filter the noise bandwidth is 2 kHz. The incoming noise on the video signal would then record as −59 dB c.c.i. at the zero-offset output and −56 dB c.c.i. at the (n ± $^1/_3$) line offset output. A small correction has to be made to these two figures because the measuring equipment uses a rectifying type detector rather than a true r.m.s. detector. Assuming that the noise is Gaussian, the noise level would be recorded 1 dB lower[4] than shown by the above calculations.

For −50 dB c.c.i., the worst-case noise margin is 10 dB for nominal zero offsets, and 7 dB for nominal (n ± $^1/_3$) line offsets. This noise margin is large enough to allow for instrumental errors, and losses in the u.h.f. feed to the measuring equipment's television receiver.

5.2 Instrumental limitations within the equipment

The spacing between the quantum levels of the 12-bit analogue-to-digital converter determines the minimum resolvable level of c.c.i. The conversion range of the a.d.c. is adjusted so that 0 dB c.c.i. would occupy the full range. For a perfect 12-bit a.d.c. the minimum resolvable signal has a peak-to-peak variation of one quantum spacing or −72 dB with respect to the conversion range of the a.d.c. The commercially made a.d.c. which is used within the equipment, although monotonic in all 12 bits, has quantum levels that are not equally spaced. The maximum difference between quantum levels can approach that from an ideal 11-bit a.d.c. Hence, the practical resolution is limited to that of an ideal 11-bit a.d.c. or −66 dB c.c.i.

When the measuring equipment is fed from a pulse-and-bar generator it records less than −66 dB c.c.i. on all outputs.

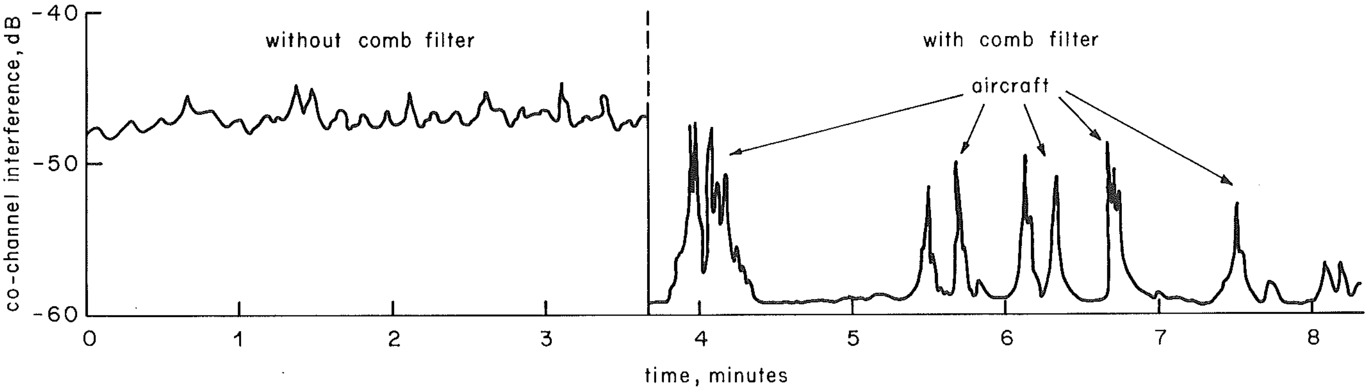

Fig. 6 - Removal of picture-dependent modulation of the sync. pulse level by the 25 Hz comb filter

5.3 Picture-dependent modulation of the level of the line synchronising pulses

The effectiveness of the 25 Hz comb filter at removing picture-dependent modulation of the sync. pulse level can be seen from Fig. 6. Fig. 6 is a chart recording made of the nominal zero offset output of the c.c.i. measuring equipment when measuring the BBC-1 transmission from Crystal Palace on Test Card. Test Card was chosen because it produces a large 'rumble' in the sync. pulse level. The left hand side of the figure was recorded without the comb filter, the right hand side with the comb filter. The comb filter had reduced the 'rumbles' by about 12 dB. The residual level of −59 dB c.c.i. is the noise level from the receiver. The level and frequency of aircraft interference may be much higher than for other parts of the country; the site at BBC Research Department is unfortunately midway between Heathrow and Gatwick Airports.

For moving pictures, one would expect the comb filter to be less efficient than for still pictures. The movement in the picture gives a similar movement to the 'rumble' in the sync. pulse level. Hence the movement 'rumble' is not completely removed by the comb filter. Tests have shown that the movement in the picture has to be fairly rapid before the rumbles again become important. Rapidly moving pictures are abnormal though, obviously, there will be some programmes where there are many fast-moving pictures and the resolution of the equipment to c.c.i. will be reduced, due to the spurious responses that rapid movement causes.

6. Accuracy of the measuring equipment

6.1 Nominal (n ± $^1/_3$) line offset interference

If the level of nominal (n ± $^1/_3$) line offset interference lies in the range −25 dB to −50 dB, the c.c.i. measuring equipment should record the level on the chart recorder within ± 4 dB.

This tolerance is made up of two parts. Firstly, instrumental inaccuracies account for ± 1 dB of the tolerance. Secondly, the variation in the mean level of interfering carrier with interfering picture content accounts for ± 3 dB of the tolerance. The measuring equipment is calibrated assuming that the mean amplitude of interfering carrier is 6 dB below the amplitude at tips of syncs. As the interfering picture content changes, then so will the mean level of interfering carrier. Hence, the mean amplitude of the beat cycle in the level of the wanted sync pulses will change. If the interfering picture is at black level, the mean amplitude of interfering carrier is 2 dB below the amplitude at tips of syncs. If the interfering picture is peak white, the mean amplitude of carrier will be 8·5 dB below the amplitude at tips of syncs. Hence, as the interfering picture content ranges, the recorded level of c.c.i. will vary by approximately ± 3 dB.

In the rare case when the line sync. pulses of the wanted and interfering pictures coincide, the equipment will record 6 dB high.

If the level of the interference is higher than −25 dB, the sync. separator within the measuring equipment may fail. However, even if it does fail, the chart recorder will always indicate a level of interference higher than −25 dB.

If the level of interference is below −50 dB, then the accuracy of the equipment is limited by the noise level on the incoming video signal. In Section 5.1 it was shown that if the noise level on the incoming video signal is 'worst-case' the resolution of the measuring equipment is limited to −50 dB.

6.2 Nominal zero offset interference

The accuracy with which the measuring equipment will record nominal zero offset interference is difficult to quote because of the action of the 25 Hz comb filter. Until the equipment has completed its field trials it is not possible to say precisely what the accuracy will be. However, it is of interest to consider all the parameters that affect the accuracy.

The level of c.c.i. that is recorded by the equipment depends on the exact offset frequency as well as the actual level of c.c.i. The measuring equipment is calibrated only at certain offset frequencies as shown in Fig. 4, at other frequencies the level will be recorded in error.

The main parameter that controls the accuracy of the c.c.i. measuring equipment is the rate of drift of the offset frequency relative to the rate of change of the actual level of c.c.i. This can easily be seen by considering possible real-life situations. Consider the case when the actual level of c.c.i. remains virtually constant whilst the offset frequency is drifting through several notches in the comb filter. In this case, the chart recording will give an accurate record of the level of c.c.i. The maximum reading on the chart is produced when the offset frequency is midway between two adjacent harmonics of 25 Hz. Hence, from Fig. 4, the actual level of c.c.i. can be found by subtracting 4 dB from the maximum reading. At the other extreme, the offset frequency could remain virtually constant whilst the actual level of c.c.i. changes. In this case, the chart recording may not give an accurate record of the actual level of c.c.i. If the offset frequency is close to a harmonic of 25 Hz then the equipment will record a very much lower level of c.c.i. than is actually present. Which one of these extremes is most representative of the situation in practice is impossible to say until the measuring equipment has completed its field trials.

The instrumental errors and errors caused by the change in interfering picture content mentioned also apply to the zero-offset case and must be included when quoting an overall accuracy. There are, however, some slight differences between the zero-offset case and the (n ± $^1/_3$) line offset case. The sync. separator can stand at least −20 dB zero offset c.c.i. before it fails. Also the resolution to zero offsets in respect of noise is 3 dB greater.

6.3 'Foreign' offset interference

The 'foreign' offset output is designed to record the level of c.c.i. on all offsets other than nominal zero or nominal (n ± $^1/_3$) line. The accuracy of this output is very similar to the accuracy for (n ± $^1/_3$) line offset interference. The only difference is the resolution in respect of noise. The noise bandwidth of the 'foreign' offset filter (see Fig. 3) is 3 kHz as opposed to 2 kHz for the (n ± $^1/_3$) line offsets filter. Hence the resolution to 'foreign' offsets is approximately 1·5 dB worse than for (n ± $^1/_3$) line offsets.

6.4 Weighted interference

The weighted-interference output is formed by resistively adding the outputs of the nominal zero, nominal (n ± $^1/_3$) line and 'foreign' offset filters according to their visibility on a television picture. It is not intended to provide an accurate record of the level of c.c.i.; this is already accomplished by the individual outputs. In general it would be used when there is more than one type of interference, so that the effect of the combination can be judged.

7. Field trials

The c.c.i. measuring equipment is now undergoing field trials. The field trials are being conducted by the Transmitter Capital Projects Department of the BBC. During the trials the equipment will be placed at various r.b.l. transmitters where c.c.i. is believed to affect reception.

The aim of the trials is to compare the amount of c.c.i. recorded by the equipment with reports of interference from viewers within the service area of the r.b.l. transmitter. Sometimes there will also be feedback from engineers at the r.b.l. site. This feedback will be more useful than the viewers reports as the engineers will have a more critical appraisal of the interference. From all the information it is hoped that the performance of the measuring equipment can be assessed. Since co-channel interference is sporadic in nature occurring normally for only a short percentage of the time, the field trials may last up to 18 months.

During the trial period various design and instrumental faults may come to light. The equipment will be modified to correct these faults during the trial period. As a result, at the end of the trial period the prototype measuring equipment should form the basis for a production model, assuming that the technique developed for measuring c.c.i. proves successful.

8. Discussion

To be able to measure the level of co-channel interference on a television signal, the beat between the wanted and interfering carriers must be separated from the picture information. In the prototype measuring equipment, this is done by sampling the video signal during the synchronising pulses. No better method has yet been suggested.

However, the technique of sampling only the sync. pulses does not in itself give sufficient isolation between the picture information and the co-channel interference. The sync. pulse level is modulated by low frequency components in the wanted picture. If this low frequency 'rumble' is not removed, the resolution to nominal zero offset c.c.i. is only 40 dB. The measuring equipment removes the sync. pulse 'rumble' by using a 25 Hz comb filter. For nominal (n ± $^1/_3$) line offsets c.c.i., the resolution is unaffected by the 'rumble'.

Field trials may show that using a 25 Hz comb filter to remove the sync. pulse 'rumble' is not a good method because correct measurement of the level of zero offset c.c.i. relies on the offset frequency between wanted and interfering carriers drifting with time. As discussed in Section 6.1 the offset frequency might in some cases drift very slowly and stay within one of the comb filter notches for hours or even days, during which time the measuring equipment would be blind to nominal zero-offset c.c.i.

Recording the output of the c.c.i. measuring equipment both with and without the comb filter may partially overcome the problem of blindspots. For example, no matter what the exact offset frequency, if the level of zero offset interference is higher than −40 dB, it can be resolved without the aid of the comb filter. Hence, recording the output both with and without the comb filter would remove any possibility of the equipment being blind to high level c.c.i. During the five or ten minute period that the measuring equipment records, the first half would be made with the comb filter, and the second half without the comb filter. The changeover can easily be done by a relay. This technique would help only if the level of zero-offset c.c.i. is higher than −40 dB. Since nominal zero-offset c.c.i. is visible down to −60 dB, the improvement would be small.

When the problem of removing picture-dependent modulation of the sync pulse level was first considered, several solutions were suggested. Using the 25 Hz comb filter was the simplest of these. All the other methods are much more complex. In the light of the results of the field trials, future models of the c.c.i. measuring equipment may have to use one of these more complex methods.

One possible method is based on the assumption that the interference beat can be separated from the sync pulse 'rumble' by a narrow bandwidth filter. In essence, the sampled sync pulses are passed through a filter with a bandwidth less than 25 Hz. The centre frequency of the filter is slowly swept over the nominal zero offset band from 0 to 1 kHz. At the end of each sweep the amplitude of the largest output from the filter during the sweep is recorded.

The frequency spectrum of the sync. pulse 'rumble' is a large number of discrete spectral lines at 25 Hz intervals. Using the above method at any time during the sweep the filter will pass energy from only one of these spectral lines. For the c.c.i. beat to be resolved, its level must be greater than only the largest of the discrete spectral lines of the sync.pulse 'rumble'.

It is reasonable to assume that no one spectral line of the sync. pulse 'rumble' contains most of the energy. Without detailed measurements it is not possible to prove this assumption; as yet no measurements have been made. However, when the waveform of the sync. pulse 'rumble' is viewed on an oscilloscope, it does not appear to have most of its energy at any one frequency. Hence, the interference would be resolvable using the above method even when submerged in a high level of sync. pulse 'rumble'.

This method has the great advantage over using the 25 Hz comb filter of having no blind spots. Even if the offset frequency between the wanted and interfering transmitters is a harmonic of 25 Hz, the equipment will still respond. The disadvantage of this method is that it may be uneconomic to instrument, requiring in effect a simple version of a spectrum analyser.

9. Conclusions

Prototype equipment has been built to measure the level of co-channel interference received by r.b.l. transmitters. The equipment uses the technique of sampling the line-synchronising pulses of the demodulated television signal.

The equipment provides three outputs for a chart recorder, corresponding to co-channel interference with the offset frequencies between wanted and interfering transmitters that are (a) nominally zero, (b) nominally (n ± $^1/_3$) line and (c) non-standard. The latter 'foreign' offset output indicates c.c.i. for all offsets other than nominal zero or nominal (n ± $^1/_3$) line.

A fourth output for the chart recorder will record the level of c.c.i. on all offsets, approximately weighted according to their visibility on a television picture.

The equipment should be able to resolve c.c.i. with nominal zero or (n ± $^1/_3$) line offsets when the protection ratio between the wanted and interfering carriers is 50 dB.

The figure for the expected resolution for nominal zero offset interference assumes that the offset frequency does not stay within a few hertz of an exact multiple of 25 Hz for any appreciable time. The validity of this assumption will be found out during field trials.

10. References

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11. Appendix

A 2·5 Hz high-pass digital filter

Fig. 7 shows a block schematic diagram of the 2·5 Hz high-pass digital filter. The filter is a first order recursive type, which operates on discrete signal samples at line scan frequency. Within the recursive loop of the filter 23-bit arithmetic is used to ensure stability and maintain 12-bit resolution in its output.

The following analysis shows that the filter has a similar frequency response to a single-time-constant high-pass resistance-capacitance network. The effective time constant of the filter is also derived.

The operation of the filter is defined by the following equations relating the input (X) output (Y) and feedback (Z) time functions shown in Fig. 7.

$$Y(nT) = X(nT) - Z(nT) \quad (1)$$
$$Z(n+1)T = Z(nT) + \delta\, Y(nT) \quad (2)$$

where T equals one clock period.

Eliminating terms in Z:

$$(1-\delta)\, Y(nT) - Y(n+1)T = X(nT) - X(n+1)T \quad (3)$$

Using complex vector notation let $X(nT) = e^{j\omega nT}$; then $Y(nT) = H(j\omega)\, e^{j\omega nT}$, where $H(j\omega)$ is the complex frequency response of the filter. Substituting these values into equation (3)

$$H(j\omega)[(1-\delta)e^{-j\omega T}-1]\, e^{j\omega(n+1)T} = [e^{-j\omega T}-1]\, e^{j\omega(n+1)T} \quad (4)$$

Therefore:-

$$H(j\omega) = \frac{1-e^{-j\omega T}}{1-ke^{-j\omega T}} \text{ where } k = 1-\delta \quad (5)$$

This is the frequency response of a high-pass filter. Since k is very close to unity, for large values of ωT, $H(j\omega) = 1$ and, for $\omega T = 0$ or an even multiple of 2π, $H(j\omega) = 0$.

When ωT is small i.e. close to the cut off frequency;

$$H(j\omega) \approx \frac{j\omega T/\delta}{1+j\omega T/\delta} \quad (6)$$

This compares with the frequency response of a single time-constant high-pass resistance-capacitance network:-

$$\frac{j\omega\tau}{1+j\omega\tau}$$ where τ is the time-constant of the resistance-capacitance network.

Hence the effective time-constant of the digital filter is $\frac{T}{\delta}$ = 65·5 ms and the – 3 dB point of the filter =

$$\frac{1}{2\pi\frac{T}{\delta}} = 2{\cdot}5 \text{ Hz}$$

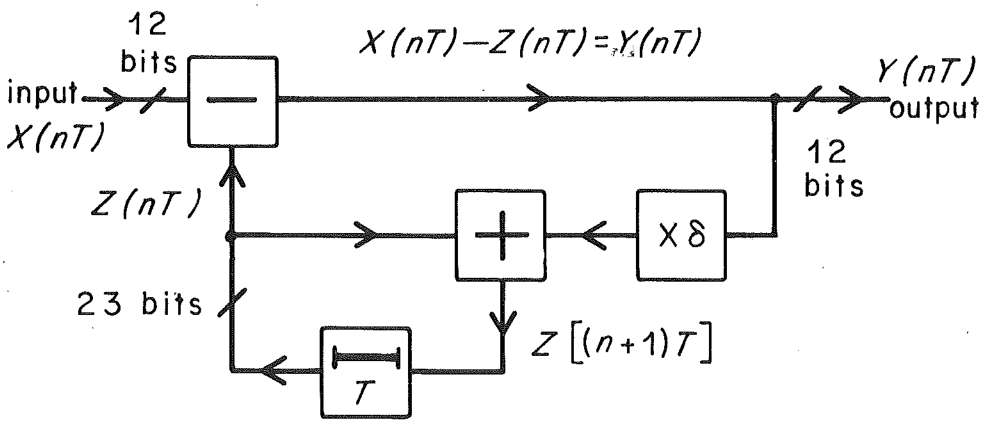

Fig. 7 - Block schematic diagram of 2·5 Hz high-pass digital filter
$\delta = 2^{-10}$ T = *Delay of one clock period (64 μs)*

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